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MODELING OF MOTION CONTROL SYSTEM FOR THE SOCCER ROBOT

Technology and Communication

2013

FOREWORD

I would like to express my sincere gratitude to all people who helped me and encouraged me during my study. Firstly, I would like to thank my thesis supervisor Dr. Yang Liu, Lecturer in Vaasa University of Applied Sciences, who gave me strength and suggestions to implement my thesis. Secondly, I would like to give my thanks to all the teachers who helped me during my study. Finally, thanks to my family, especially my younger sister, and my friends who also gave me great support and assistance.

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22, April, 2013

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ABSTRACT

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Title	Modeling of Motion Control System for the Soccer Robot
Year	2013
Language	English
Pages	52 + 3 Appendices
Name of Supervisor	Yang Liu

In recent years, Robocup competition has shown great activities in high-tech field. With the development of the soccer robot, it is necessary and convenient for people to simulate the motion situation of robot. Therefore, this thesis builds a simulation model of motion control system for botnia soccer robot (robocup small size league robot) with MATLAB/Simulink. The entire thesis consists of 5 parts: 1) Background study; 2) Motor and drive system modeling; 3) Velocity distribution and composition; 4) Robot displacement modeling; 5) Testing and result. Moreover, the motion control system uses three closed-loop controls: speed loop controlled by PID controller, current loop adjusted by current hysteresis regulator and position feedback detected by hall sensors, which implement the accuracy of the whole system. During the testing, the result shows the right motion regular according to the setting velocity. Therefore, based on the coincidence of the simulation results and theory analysis, we can draw the conclusion that the whole modeling system can support the simulation of the soccer robot motion control. Besides, it develops an advanced design and a debugging scheme for the real soccer robot motion control system.

Keywords Brushless DC Motor, Motion Control, Robocup.

CONTENTS

LIST OF FIGURES AND TABLES

LIST OF ABBREVIATIONS

BLDC	Brushless Direct Current
BACK-EMF	Back Electromotive Force
DC	Direct Current
EMF	Electromotive Force
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistor
PWM	Pulse-width Modulation
PID	Proportional, Integral and Derivative
RPM	Revolutions per minute

1 INTRODUCTION

In recent years, Robocup competition has gained great popularity in high-tech field. With the development of the soccer robot, it is necessary to simulate the motion of the robot. Therefore, this thesis built a simulation model of the motion control system for Botnia soccer robot (robocup small size league robot) with MATLAB/Simulink.

The thesis consists of five parts: 1) Background study; 2) Motor and drive system modeling; 3) Velocity distribution and composition; 4) Robot displacement modeling; 5) Testing and result.

1.1 Background study

At the very beginning, the background information of robot was studied including the structure of robot, drive system of motor, mechanism and parameters of motor and working process of the whole system. In the background study, all of these and the modeling tool were briefly introduced.

1.2 Modeling of Drive System of Brushless DC Motor

Based on the analysis of the mathematical model of BLDC, an effective method for modeling and simulation of the BLDC control system was proposed. During the drive system modeling part, a simulation model of BLDC control system with MATLAB/simulation was built, and the sub-modules of the controlling system introduced in detail.

1.3 Modeling of Velocity Distribution and Velocity Composition

The velocity distribution and composition part introduces the method of how to distribute the velocity vectors of the robot to each wheel and synthesize the feedback velocities after the operating of motors. This part is based on the Embedded Matlab Function model.

1.4 Modeling of robot displacement

The robot displacement modeling part obtains the displacement of robot by analyzing the linear speed. A simple test model has been built to verify the entire motion system.

1.5 Testing and result

The testing and result part includes the testing and result analysis of motor and motion system of robot. The clear results are presented in this part which verifies the correctness of the motion system. The reasonability and validity were tested by the coincidence of the simulation, experimentation results and theory analysis.

1.6 Thesis overview

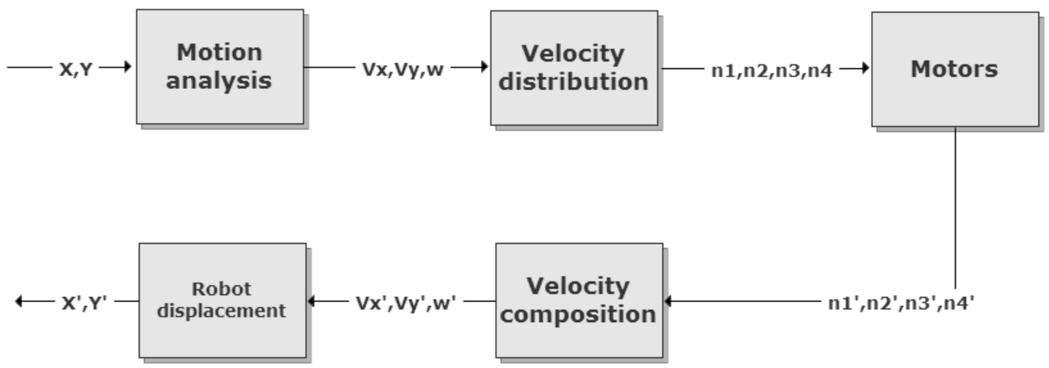

Figure 1. Thesis overview

Figure 1 shows the outline of the thesis from motion trace setting to the real displacement obtaining. It contains five parts: motion analysis, velocity distribution, motor operating, velocity composition and robot displacement calculation.

2 BACKGROUND STUDY

In this chapter, the modeling tool and background of robocup small size league, structure of robot, drive system of motor, mechanism and parameters of motor and working process of the whole system are briefly introduced.

2.1 Modeling tool

Simulink® is a block diagram environment for multi-domain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with MATLAB®, enabling you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis/7/ Therefore, Simulink® is a good choice to build and simulate the soccer robot motion control system as the modeling tool. In addition, it is easy and convenient to generate the code automatically by Simulink which is a potential method for the deeper development of the soccer robot.

2.2 Brief introduction of Robocup Small Size League

Robocup is an international robotics competition founded in 1997. The aim is to promote and encourage robotics and AI research, by offering a publicly appealing competition with full of challenge. The RoboCup Small Size League (SSL) is one of the Robocup soccer leagues. This league involves teams of five small robots, each up to 18cm in diameter and up to 15cm height. The robot teams are entered into a competition to play a type of soccer against opponent teams fielded by other research groups. Two halves of 15 minutes each are played, and during a game no human input is allowed. /1/

Each robot is Omni-directional. Figure 2 shows the under stratum of the small size league soccer robot, which contains four wheels distributed on the circumambience. Each wheel is driven by a 30 watt brushless motor and featuring an electromagnetic encoder.

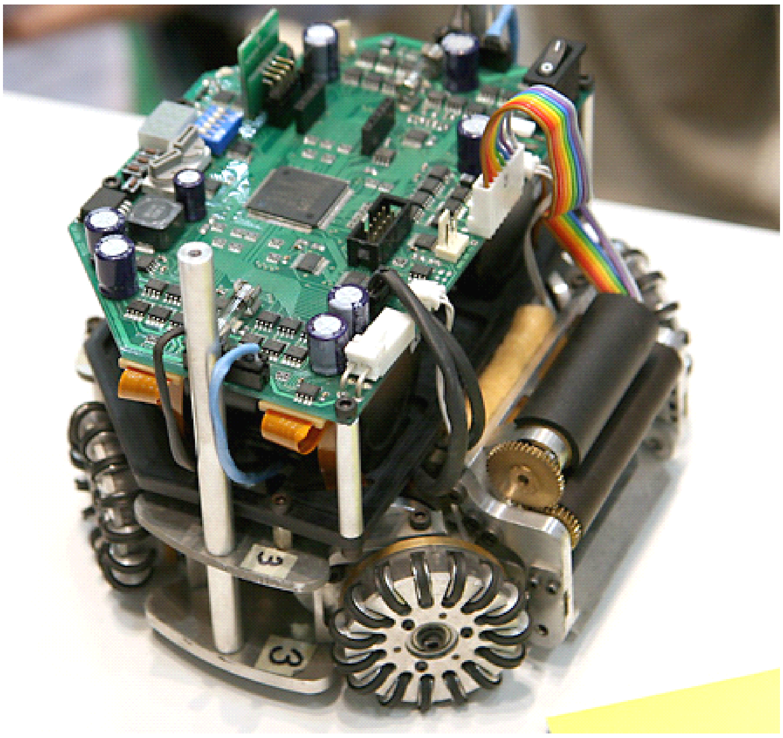

Figure 2. Small Size League soccer robot /2/

2.3 Mechanism of Brushless motor

Brushless DC electric motors (BLDC motors) are synchronous commutated motors which are powered by a DC power source via an integrated inverter power supply, which produces an AC electric signal to drive the motor. AC, alternating current, does not imply a sinusoidal waveform but rather a bi-directional current with no restriction on waveform. Additional sensors and electronics control the inverter output waveform amplitude and frequency. The most important characteristic of the Brushless DC motor is it does not has electric brush and commutator. Therefore, the Brushless DC motor has the advantage of no commutation spark, credibility and safety of operation, long useful time, etc.

2.3.1 The structure of Brushless DC motor

The brushed DC motor has a rotating armature and fixed magnetic field and it uses electric brush and commutator to change the direction. However, the brushless DC motor has a rotating magnetic field and fixed armature and uses the position sensor to detect the position of rotor. According to the position signals of rotor, the electronic commutation circuit accomplishes the phase changing and generates PWM pulses to drive the motor.

The main components of the BLDC motor are the stator with armature winding installed and the rotor with a permanent magnet. Figure 3 shows the construction of brushless DC motor.

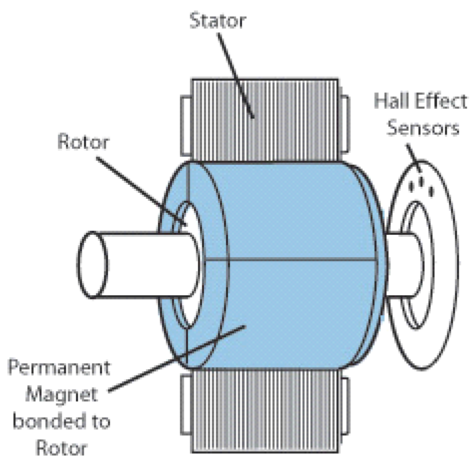

Figure 3. BLDC motor construction /4/

As we can see in Figure 3, hall effect sensors are installed on the motor. Hall sensors play the role of detecting the magnetic pole position of the rotor in the brushless DC motor, which are mounted in the corresponding position of the stator coil. When a phase of the stator winding is energized, the torque is generated by the interaction of the current and the magnetic field which is generated by rotor magnetic poles and drives the rotor to rotate. After that, convent rotor magnetic pole position signal to electric signal by the position sensor to control the electronic commutation circuit. Then the stator windings of each phase would be energized in a certain sequence, so that the stator's phase current could commutate according to the change of the rotor position and the motor can work constantly.

Another important component is the electronic commutation circuit. The electronic commutation circuit works together with position sensors to achieve the commutation. The role of electronic commutation circuit is to analyse the signals generated by the position sensor and generate the pulses to trigger MOSFETs, making the armature windings to be nergized in a certain order and ensure the reliable operation of the motor.

2.3.2 The working process of the Brushless DC motor

The working principle of the BLDC is to drive the power switching devices to make the windings energized in a certain order to generate rotating magnetic field and to make the rotor work based on the signals obtained from the position sensor. With the rotation of the rotor, the rotor position signal changes regularity, thus changing the energization state of the armature windings and converting the mechanical energy to electric energy.

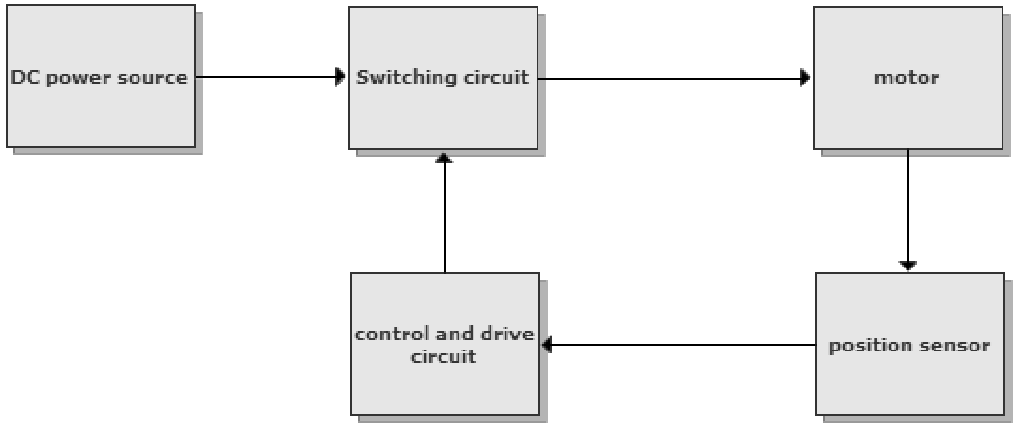

Figure 4. The working process of BLDC

There are two types of drive, half-bridge driver and full-bridge driver. The full-bridge driver has two connection methods, star connection and delta connection. Among of these, the full-bridge driver with star connection is the most useful energizing method. Figure 5 shows the full-bridge drive method with star connection for brushless DC motor.

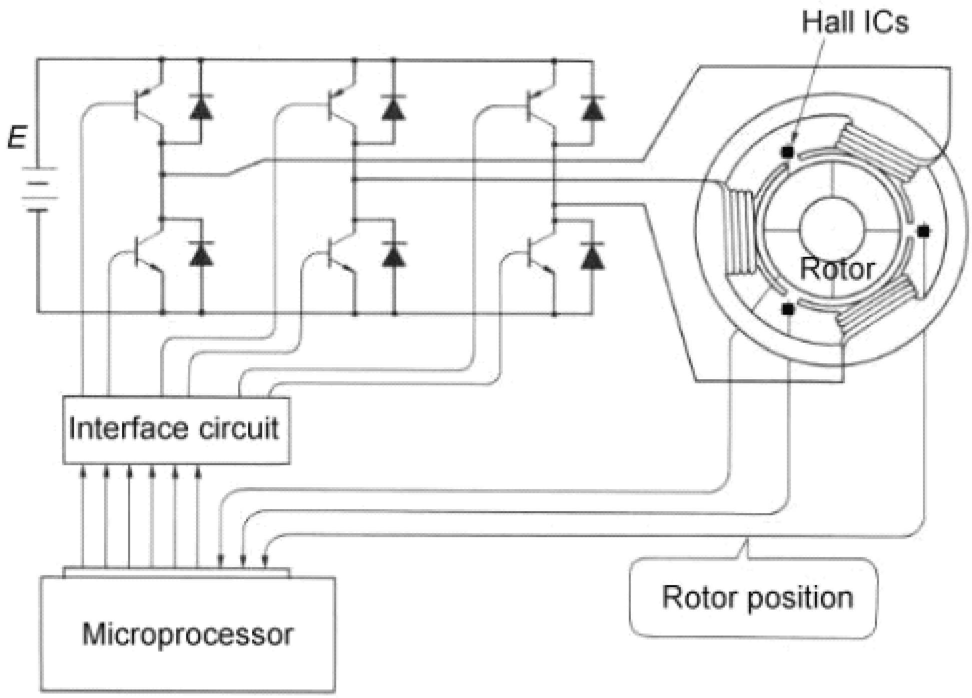

Figure 5. Brushless DC motor driver circuit /5/

There are six MOSFETs connected in the star connection method, used for controlling the energizing of the stator windings. The rotor position sensors detect the position signals and pass them to the microprocessor control circuit and after the analysis of the position signals, generate the control signals to control the switching of MOSFETs. That is the process of inversion.

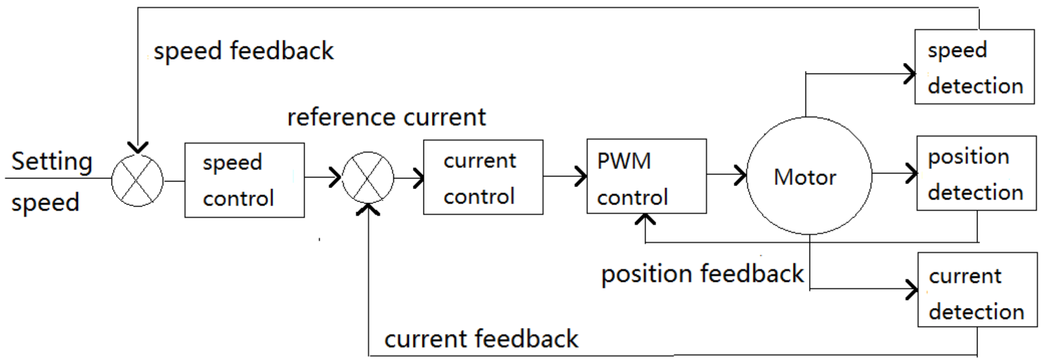

Figure 6. Closed-loop control

The system uses the closed-loop control structure with the series connection of speed adjuster and current adjuster. The role of the speed regulator is the speed adjustment and making no static error in the steady state, its output limit determines the maximum current allowed in the current control. The role of the current regulator is current following, overcurrent protection and inhibition of voltage disturbances in a timely manner.

2.3.3 Motor & Motor Parameters

The Maxon™ EC 45 Flat DC motor (30W) is used as the motor source. According to the datasheet, there are some critical parameters that should be noticed (see Figure 7).

Motor Data			
	Values at nominal voltage		
1	Nominal voltage	V	12.0
2	No load speed	rpm	4370
3	No load current	mA	151
4	Nominal speed	rpm	2860
5	Nominal torque (max. continuous torque)	mNm	59.0
6	Nominal current (max. continuous current)	A	2.14
7	Stall torque	mNm	255
8	Starting current	A	10.0
9	Max. efficiency	%	77
	Characteristics		
10	Terminal resistance phase to phase	Ω	1.20
11	Terminal inductance phase to phase	mH	0.560
12	Torque constant	mNm / A	25.5
13	Speed constant	rpm / V	374
14	Speed / torque gradient	rpm / mNm	17.6
15	Mechanical time constant	ms	17.1
16	Rotor inertia	gcm^2	92.5

Figure 7. Maxon™ EC 45 Flat datasheet /6/

Figure 7 shows the main parameters of the Maxon™ EC 45 Flat motor which is used for the Simulink modeling of the motor and explained in the following chapters.

3 MODELING OF DRIVE SYSTEM OF BRUSHLESS DC MOTOR

In this chapter, mathematic knowledge of the brushless DC model is introduced first. Then the simulation model of the BLDC control system with MATLAB/Simulink and its building is explained, and the sub-modules of the controlling system are introduced in detail.

3.1 Modeling of Brushless DC Motor

Firstly, the mathematic background of Brushless DC motor has been introduced. Based on the mathematic model, the simulation model of Brushless DC motor has been built and also introduced the sub-modules in detail.

3.1.1 Mathematic Modeling of Brushless DC Motor

Next, the mathematic model of the Brushless DC motor is introduced, including the voltage equation, torque equation and motion equation.

3.1.1.1 Voltage Equation

According to the Kirchhoff's voltage law, the voltage equation of three-phase winding can be shown as follows:

$$\begin{bmatrix} u_A \\ u_B \\ u_C \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} L-M & & \\ & L-M & \\ & & L-M \end{bmatrix} P \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} e_A \\ e_B \\ e_C \end{bmatrix}$$

Equation1.

Where,

u_A、u_B、u_C : phase winding voltage of stator(V);

i_A、i_B、i_C : phase winding current of stator(A);

e_A、e_B、e_C : phase winding Electromotive force(V);

Where

R is phase resistance (Ω);

L is Self-inductance (H);

M isMutual inductance (H);

P is Differential operator, P=d/dt.

The following is the equivalent circuit of voltage equation:

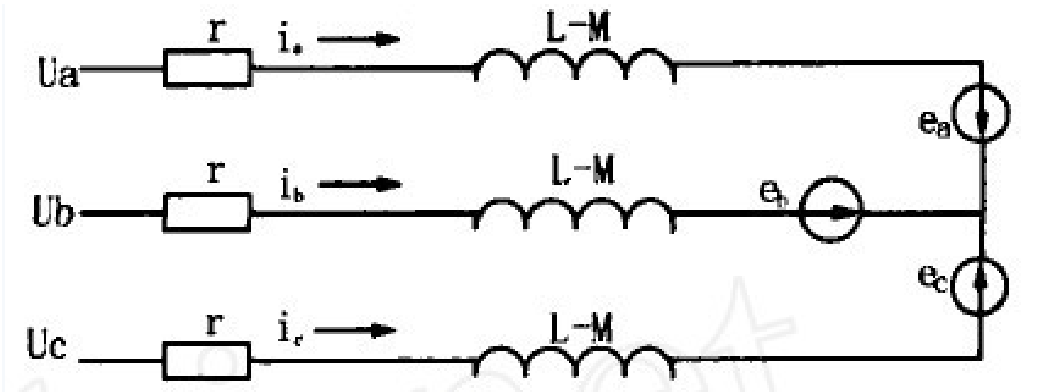

Figure 8 Equivalent circuit of voltage equation /3/

3.1.1.2 Torque Equation

The relationship between the output power of stator winding and torque:

$$Ea * Ia + Eb * Ib + Ec * Ic = T * \omega \qquad \text{Equation 2}$$

Therefore the torque equation is:

$$T = (Ea * Ia + Eb * Ib + Ec * Ic) / \omega \qquad \text{Equation 3}$$

Where

W is angular velocity(rad/s).

3.1.1.3 Motion Equation

$T - T_L = J * (d\omega / dt)$ Equation 4

Where

T_L is Load torque (N*m);

J is Rotor inertia (kg*m^2).

3.1.2 Modeling of Brushless DC Motor by Simulink

According to the mathematic modeling, the brushless DC motor can be built by Simulink.

3.1.2.1 Voltage Equation Module

Based on the voltage equation, it can be built as follows:

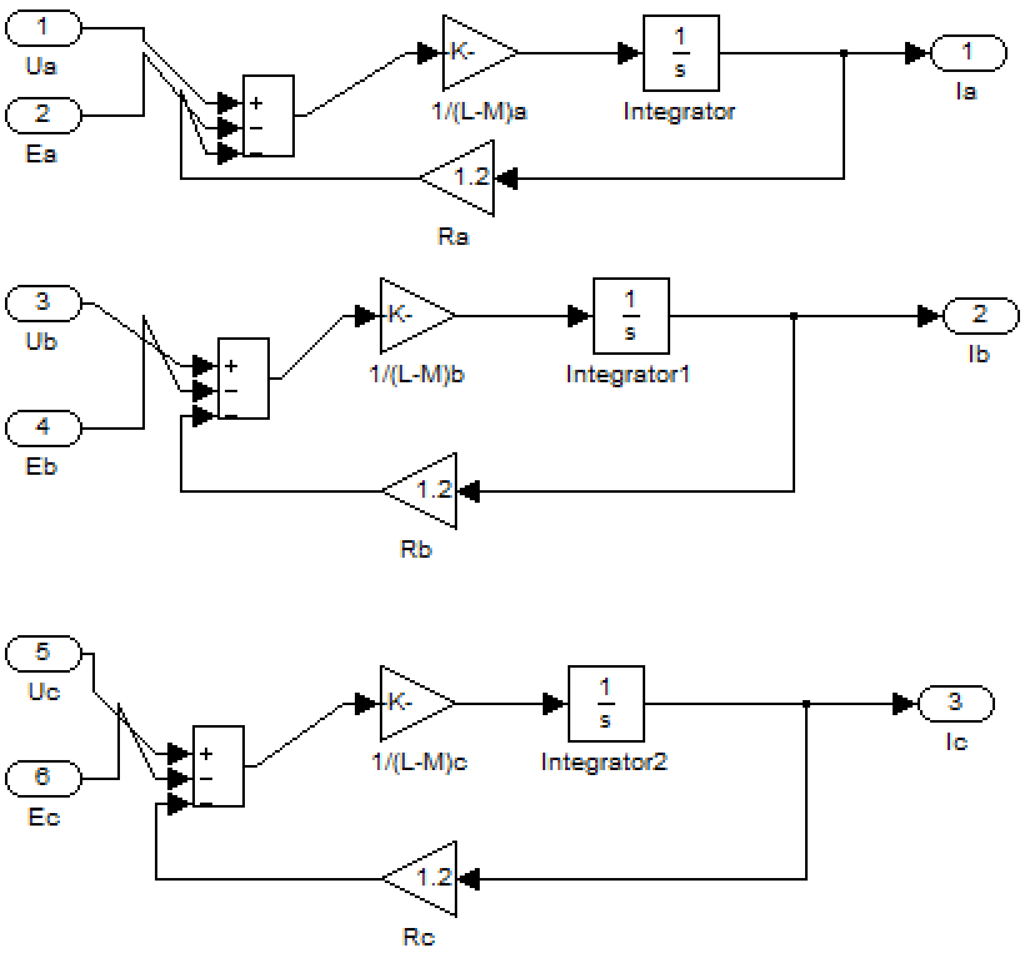

Figure 9. Voltage equation module

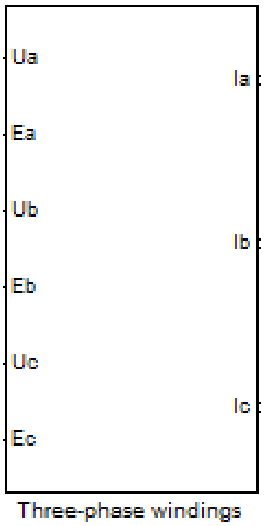

Figure 10. Voltage equation module package

3.1.2.2 Back-EMF Module

The piecewise linear method is a useful way to get the value of Back-EMF. It means that the working cycle of the motor can be divided to six parts, for each phase winding, 60° is an operational phase and every phase is linear. Moreover, each phase has a 120° difference. According to the position of the rotor and the value of rotational speed, the waveform of the Back-EMF can be determined.

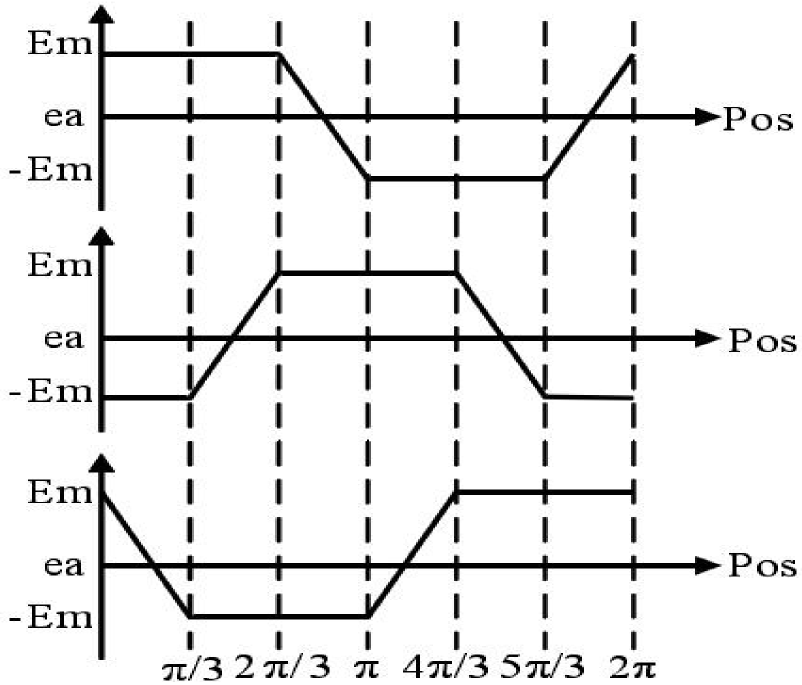

Figure 11. EMF waveform

As shown in Figure 11, the Lookup Table is created. The position signal is passed to the Lookup Table model and multiplied by rotational speed. After that, the signal of Back-EMF can be obtained. Figure 12 shows the Simulink module of Back-EMF.

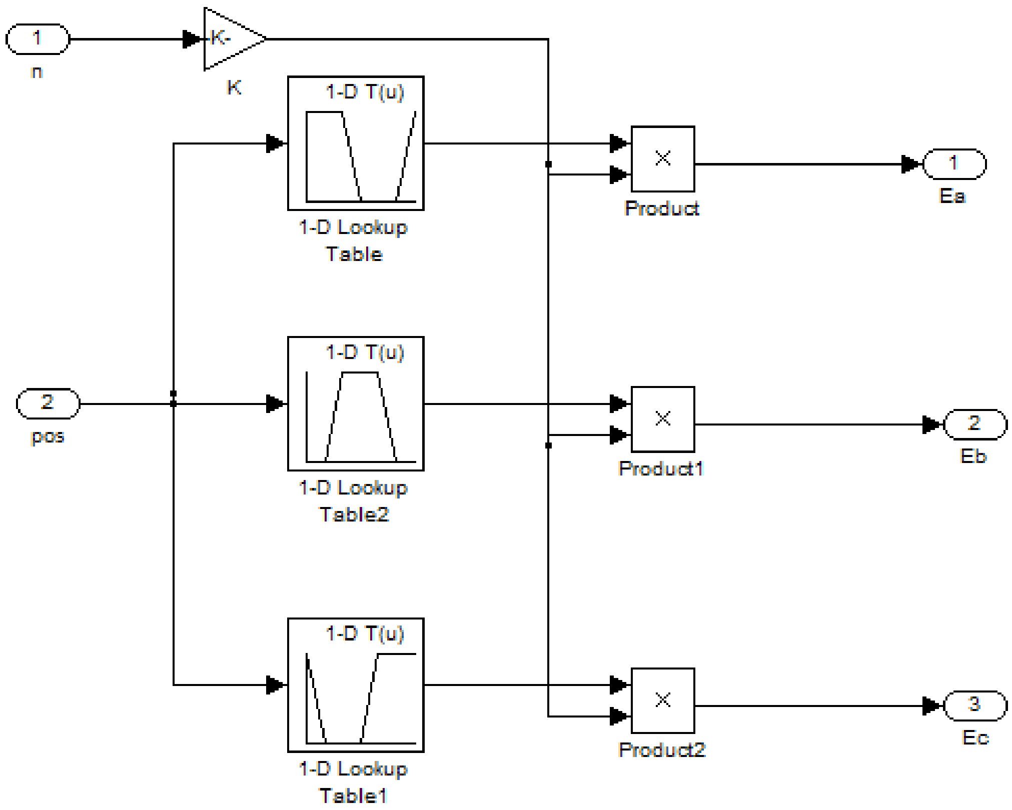

Figure 12. Back-emf module

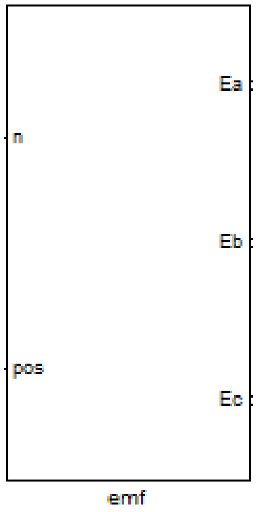

Figure 13. Back-emf module package

3.1.2.3 Torque Module

Based on the torque and motion equations, the rotational speed and position of the rotor can be calculated which is used in the Back-EMF Module. The torque module can be built as follows:

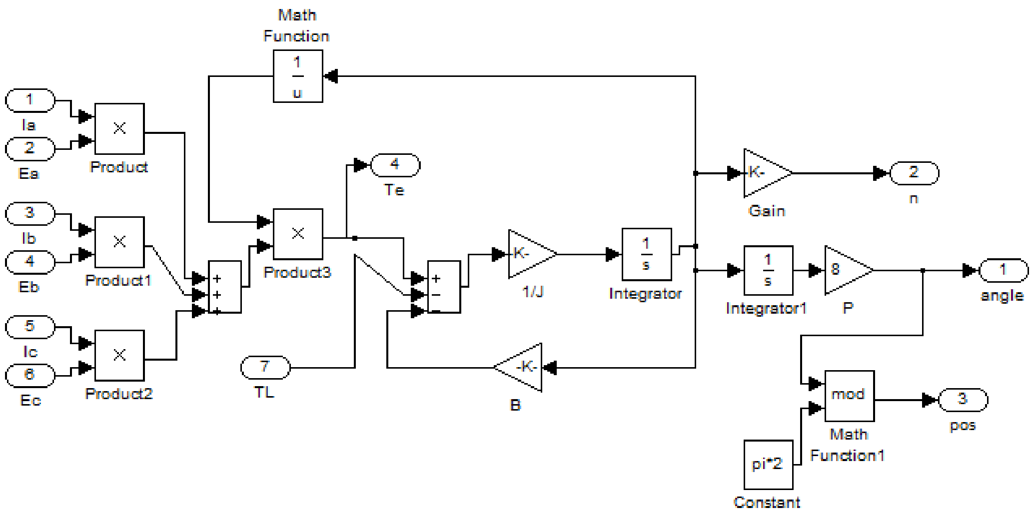

Figure 14. Torque module

The range of the position: 0~2Ω.

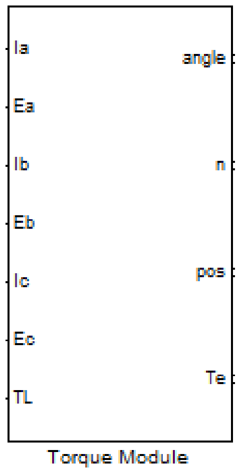

Figure 15. Torque module package

3.1.2.4 BLDC Motor Module

As a result, the Voltage Equation Module, Back-EMF Module and Torque Module can be connected as a completed Brushless DC Motor, as shown in Figure 16.

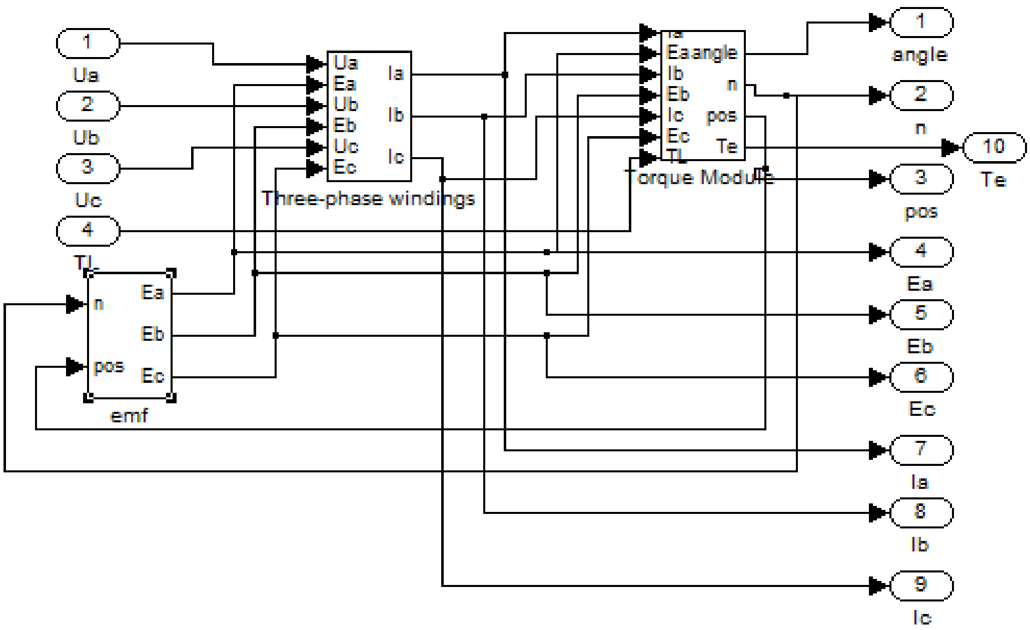

Figure 16. Brushless DC motor module

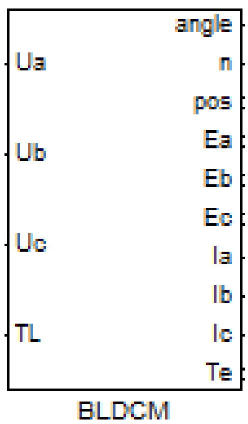

Figure 17. Brushless DC motor module package

3.2 Modeling of Drive System

The drive system consists of three closed-loop controls: speed loop controlled by the PID controller, current loop adjusted by the current hysteresis regulator and position detected by the hall sensor.

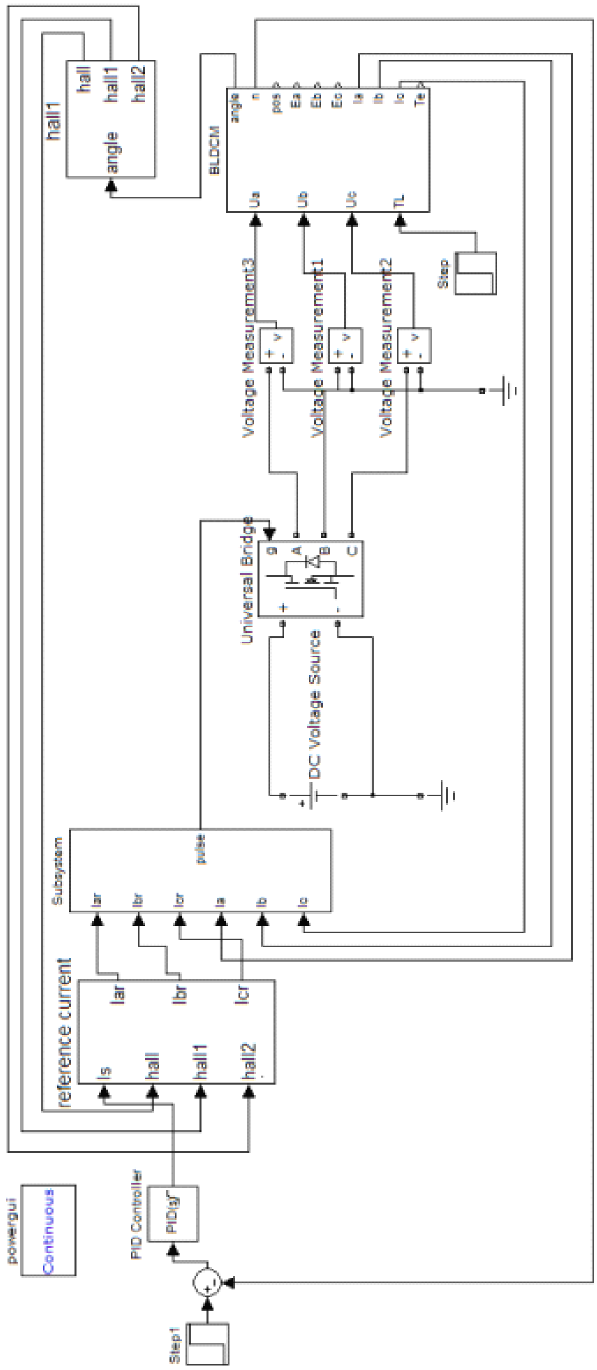

Figure 18. Drive system modeling

Firstly, the deviation e is obtained by comparing the setting signal and actual signal of rotational speed, and by passing the deviation e to PID controller, the amplitude signal of current Is can be calculated. Secondly, reference current module uses the input Is and the hall signals detected by the hall sensor to calculate each phase's reference current (iar, ibr, icr) and then the pulse generator module generates the PWM signals(pulses) through current hysteresis regulator and achieves the actual currents(ia, ib, ic) which follow the reference currents. Thirdly, the PWM signals are used to control the inverter conditions of the universal bridge, on or off, and generate the phase voltage (Ua, Ub, Uc) of motor is generated. Finally, after the operating of the BLDC, the signals of rotational speed, current and position (hall signals) can be calculated and used as feedback for the closed loop controlling.

3.2.1 Rotation Speed Control Module

The rotation speed control module can be built as follows:

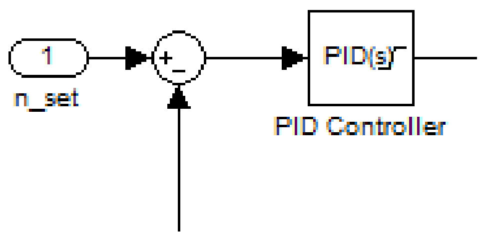

Figure 19. Rotation speed control module

The PID controller is a useful tool for speed controlling. The deviation e can be obtained by comparing the setting signal and actual signal of rotational speed, after the calculation by the PID controller, the amplitude signal of current Is can be obtained as the input signal of reference current module.

The PID controller involves three separate constant parameters: the proportional, the integral and derivative values, denoted P, I, and D. Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. Therefore, for motor controlling, P and I parameters are needed. It is not necessary to use D adjustment; the motor would be dangerous if the differential adjustment was used. After the operating of the PID controller, the system can be more stable and reliable.

3.2.2 Reference Current Module

In order to obtain the reference current, the hall signals have to be analysed first.. After combining with the current amplitude signal, the phase reference currents can be calculated. The reference current module can be built as follows:

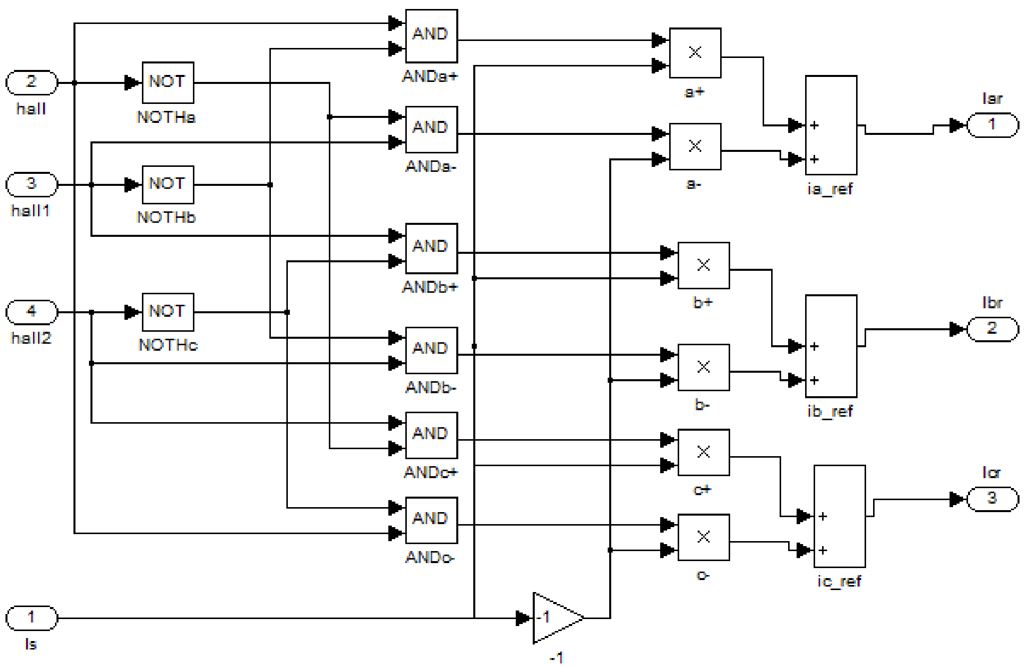

Figure 20. Reference current module

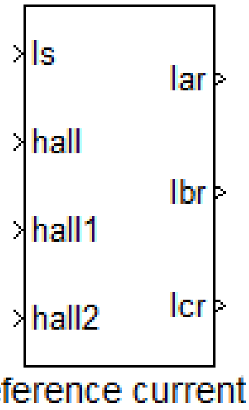

Figure 21. Reference current module package

The correspondence between hall signals and reference currents can be shown as follows:

Table 1. Relationship between hall signals and reference currents

Hall signals	Iar	Ibr	Icr
101	Is	-Is	0
100	Is	0	-Is
110	0	Is	-Is
010	– Is	Is	0
011	-Is	0	Is
001	0	– Is	Is

3.2.3 Pulse Generator Module

As shown in Figure 22, when the instantaneous value of actual current reaches the top edge of the hysteresis width, the value of PWM pulse will be low, the switching device off and then the actual value of current will be decreased. Otherwise, when the instantaneous value of actual current reaches the bottom edge of the hysteresis width, the value of PWM pulse will be high, the switching device on and then the actual value of current will be increased. In this way, the actual current can follow the reference current.

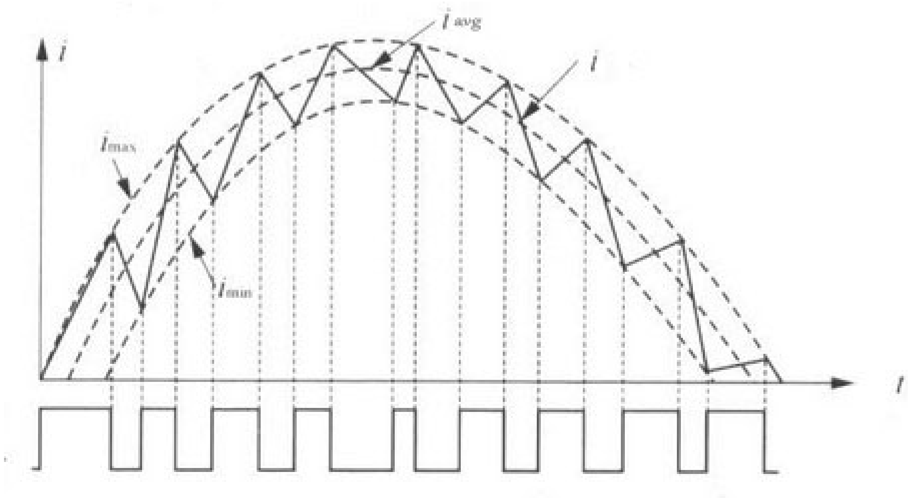

Figure 22. Current hysteresis theory

The Pulse generator module can be built as follows:

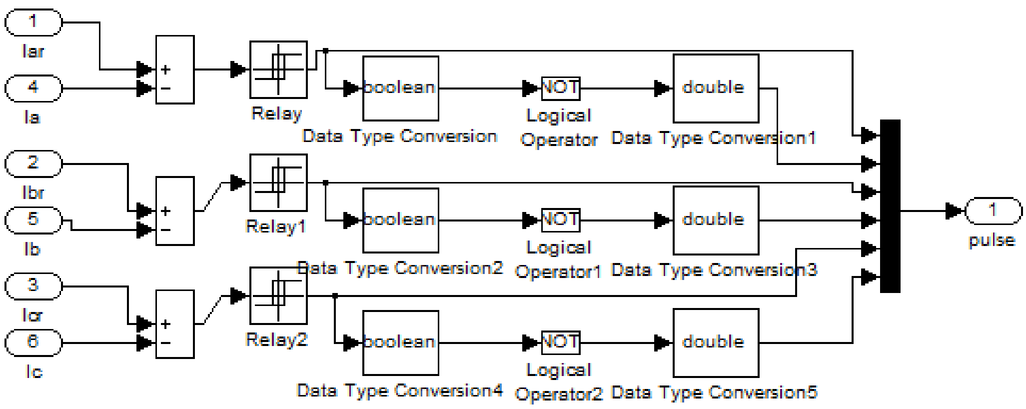

Figure 23. Pulse generator module

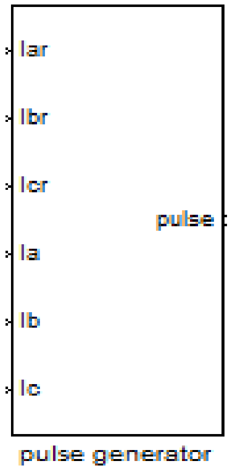

Figure 24. Pulse generator module package

3.2.4 Voltage Inverter Module

The voltage inverter used by this drive system is a DC/DC convert device that adjusts the input voltage of motor under the controlling of the PWM pulses.

As shown in Figure 24, the voltage inverter module consists of the DC voltage source and the universal bridge inverter, choose three bridge arms and MOSFET as the power electronic device. As the module in the SimPowerSystems tool box cannot connect with the module in the Simulink tool box directly, three Voltage Measurement models have to be added between the Universal Bridge Inverter and BLDC motors.

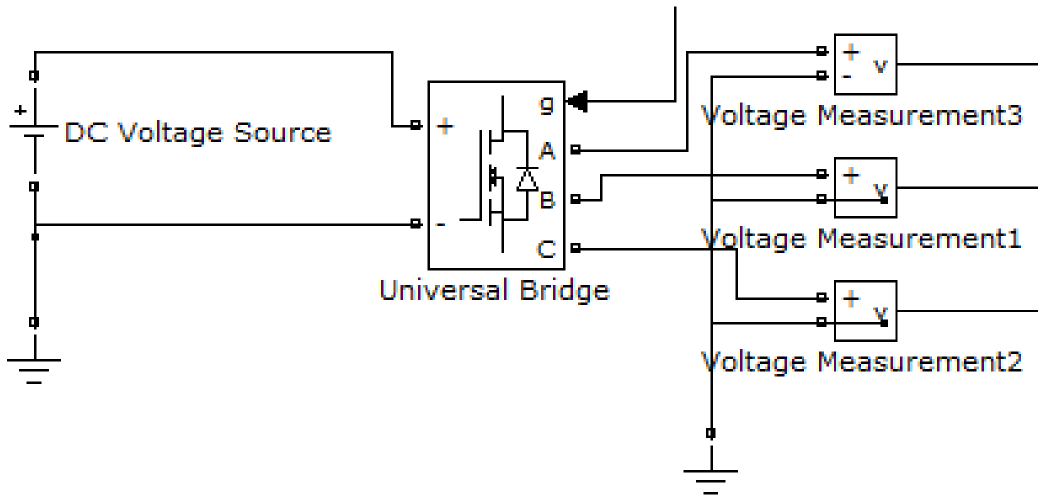

Figure 25. Voltage inverter module

4 MODELING OF VELOCITY DISTRIBUTION AND VELOCITY COMPOSITION

When the robot receives a motion requirement, at first, it should distribute the velocity vector, then pass the value of distributed velocity to each motor, after that, synthesize the feedback rotation speed from motor. In addition, the PID controllers are used to adjust the input velocities (Vx, Vy, w).

The equation between the linear velocity of the wheel and the rotation speed is:

$N = 9.55 * V/r \ (N = (60/2\Omega) * V/r)$ Equation 5.

where

N is rotation speed (rpm);

V is linear velocity of the wheel (m/s);

R is the radius of the robot wheel (m).

The modeling of velocity distribution and velocity composition can be built as follows:

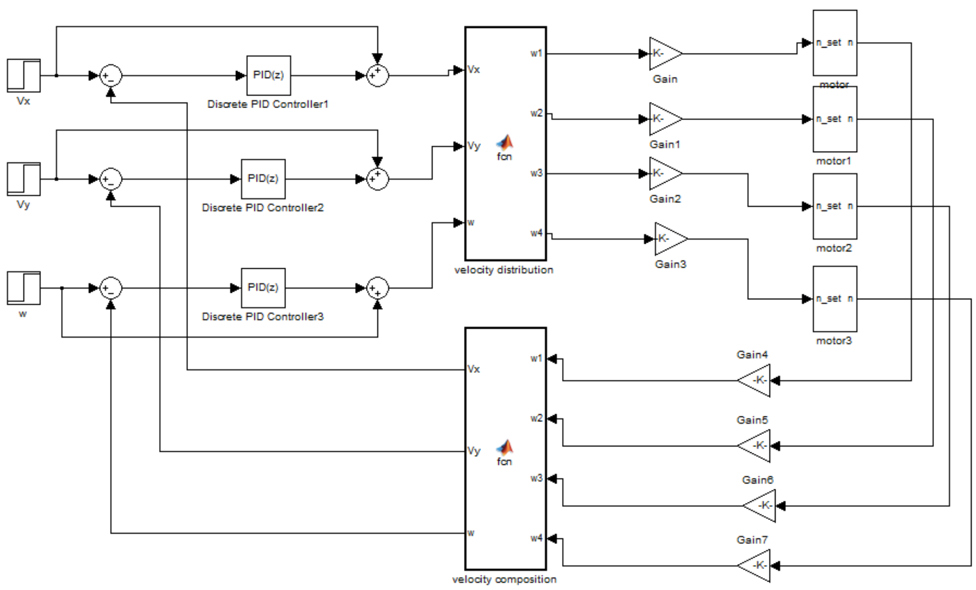

Figure 26. Velocity distribution and composition

4.1 Velocity Distribution

Assuming the velocity vectors of robot are Vx, Vy, W, as shown in Figure 27, the schematic diagram of the velocity distribution, then the speed equations of each wheel can be obtained as follows:

$$V_1 = -V_x * \cos\delta_1 - V_y * \sin\delta_1 + \omega * R \qquad \text{Equation 6}$$

$$V_2 = -V_x * \sin\delta_2 + V_y * \cos\delta_2 + \omega * R \qquad \text{Equation 7}$$

$$V_3 = V_x * \sin\delta_2 + V_y * \cos\delta_2 + \omega * R \qquad \text{Equation 8}$$

$$V_4 = V_x * \cos\delta_1 - V_y * \sin\delta_1 + \omega * R \qquad \text{Equation 9}$$

Where

R is radius of the robot, from robot center to wheel.

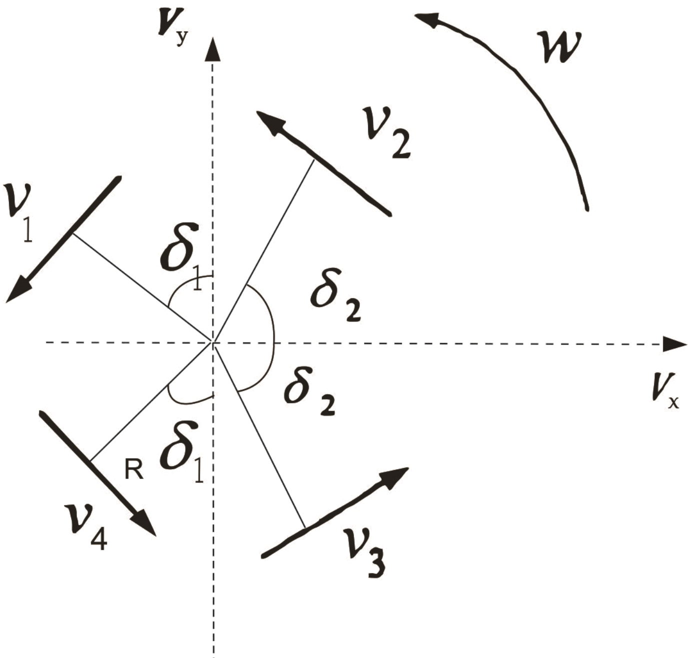

Figure 27. Velocity distribution

It is a useful method that uses the Embedded Matlab Function module to implement the velocity distribution of the robot. The following is the Matlab function:

```
function [w1,w2,w3,w4] = fcn(Vx,Vy,w)

w1 = -cos(45*pi/180)*Vx-sin(45*pi/180)*Vy+0.078*w;

w2 = -sin(54*pi/180)*Vx+cos(54*pi/180)*Vy+0.078*w;

w3 = sin(54*pi/180)*Vx+cos(54*pi/180)*Vy+0.078*w;

w4 = cos(45*pi/180)*Vx-sin(45*pi/180)*Vy+0.078*w;
```

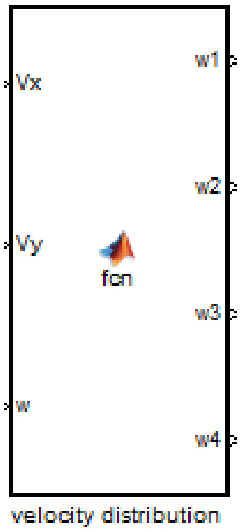

Figure 28. Velocity distribution package

4.2 Velocity Composition

After the operation of the motor, the feedback rotation speeds should be synthesized to Vx, Vy and w as the feedback of the setting linear speed vectors of the robot.

Based on the equations 6-9, the composite velocity can be obtained as follows:

$V_x = (\omega_4 - \omega_1)/(2 * \cos\delta_1)$ Equation 10.

$$V_y = ((\sin\delta_2 - \cos\delta_1) * \omega_4 - (\sin\delta_2 + \cos\delta_1) * \omega_1 + 2 * \cos\delta_1 * \omega_2)/(2 * \cos\delta_1 * (\sin\delta_1 + \cos\delta_2)) \quad \text{Equation 11.}$$

$$\omega = (\omega_1 + \omega_4 + 2 * \sin\delta_1 * V_y)/(2 * R) \quad \text{Equation 12.}$$

The velocity composition module can be also achieved by using an Embedded Matlab Function. The following is the Matlab function:

```
function [Vx,Vy,w] = fcn(w1,w2,w3,w4)

Vx=-(w1-w4)/(2*cos(45*pi/180));

Vy=((sin(54*pi/180)-cos(45*pi/180))*w4-
(sin(54*pi/180)+cos(45*pi/180))*w1+2*cos(45*pi/180)*w2)/(2*cos(45*pi/180)*(
sin(45*pi/180)+cos(54*pi/180)));

w=(w1+w4+2*sin(45*pi/180)*Vy)/(2*0.078);
```

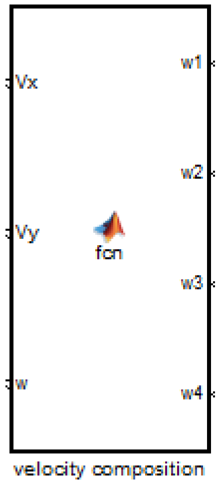

Figure 29. Velocity composition package

5 MODELING OF ROBOT DISPLACEMENT

5.1 Displacement Analysis and Modeling

The displacement of the robot can be obtained by analysing the velocities (Vx, Vy, w). The speed and displacement formulas are as follows:

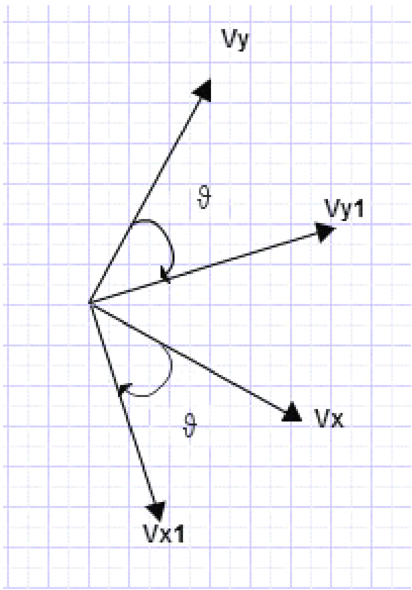

Figure 30. Velocity analysis

$$Vx_1 = Vx * \cos(\theta) - Vy * \sin(\theta)$$ Equation 12.

$$Vy_1 = Vx * \sin(\theta) + Vy * \cos(\theta)$$ Equation 13.

$$X = \int Vx_1 dt$$ Equation 14.

$$Y = \int Vy_1 dt$$ Equation 15.

$$\theta = \omega * t$$ Equation 16.

The Embedded Matlab function model is useful for distributing and synthesizing the linear speed and the Matlab code of position model can be written as follows:

```
function [Vx1,Vy1] = fcn(Vx,Vy,the)

Vx1=Vx*cos(the)-Vy*sin(the);

Vy1=Vx*sin(the)+Vy*cos(the);
```

The displacement model can be built as follows:

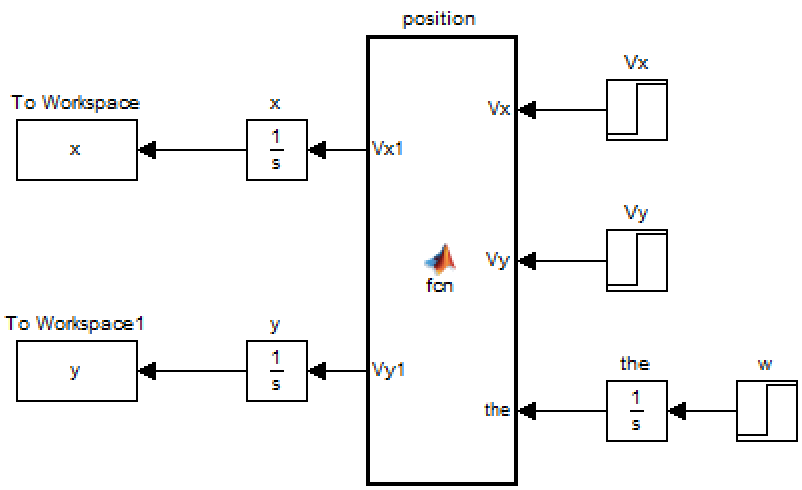

Figure 31. Displacement model

5.2 Position Setting and Testing Model

In order to test the whole system, four positions were set for the robot which generate a rectangle path. The coordinate sequence of the positions is (0,0); (0,1); (1,1); (1,0); (0,0). The Embedded Matlab Function model has been used to create the robot route. The robot motion process was described by writing the matlab code and packaged by Embedded Matlab Function model, and thus the testing model can be obtained. The following figure describes the position setting and testing model:

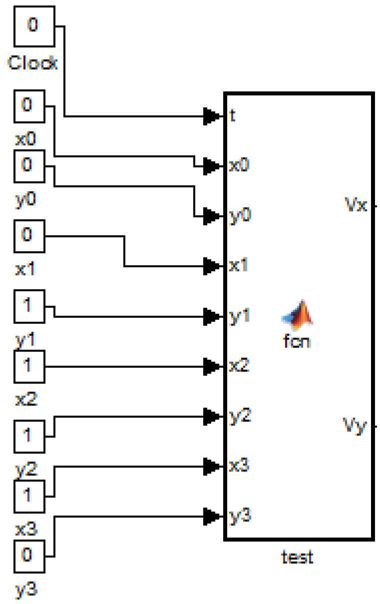

Figure 32. Testing module

After modeling of all the components, the whole system can be connected as follows:

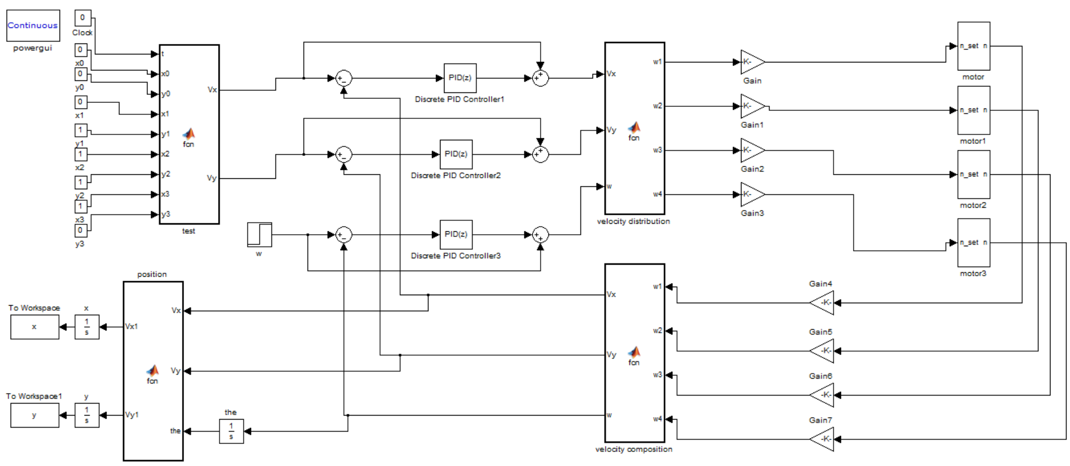

Figure 33. Robot motion system

Firstly, the position and path of the robot are set and the current value of linear speed analysed. Secondly, the linear speed of the robot is distributed to separate wheels and the distributed speed passed to each motor. Thirdly, each motor work and give feedback of the rotational speed. After that, the rotational speed is synthesized and the real path of the robot is generated .

6 TESTING AND RESULT

First, the performance of brushless motor was tested and the result of electromotive force, winding current, rotational speed, and hall signals and rotation angle were obtained Secondly, the whole system was tested and the difference between the setting value and real value of linear velocity and rotational speed is compared

6.1 Testing of Brushless DC Motor

For testing, the rotational speed n was set to equal 1000 rad/s and step time as 0.01. For the PID parameters, P was set to equal 0.5, I to 0.25 and D to 0. After the operating of motor, the result can be obtained.

6.1.1 Result of the Electromotive Force (EMF)

The following figure describes the waveforms of electromotive force:

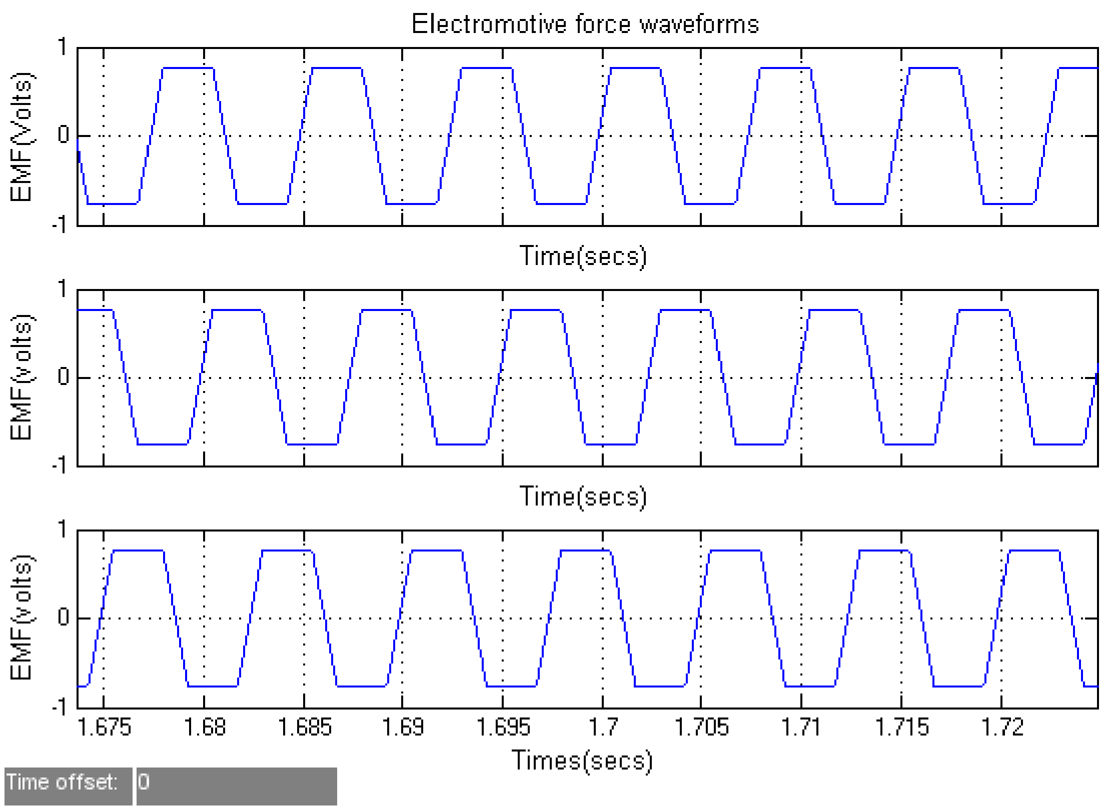

Figure 34. Electromotive force waveforms

As we can see in Figure 34, the waveforms of the back-emf signals have followed a cyclical pattern and each phase has a 120° difference. It has the same situation with the real back-emf signals in real life, which means that using the piecewise linear method to get back-emf signals is reasonable.

6.1.2 Result of the Winding Currents

The following figure shows the waveform of winding currents:

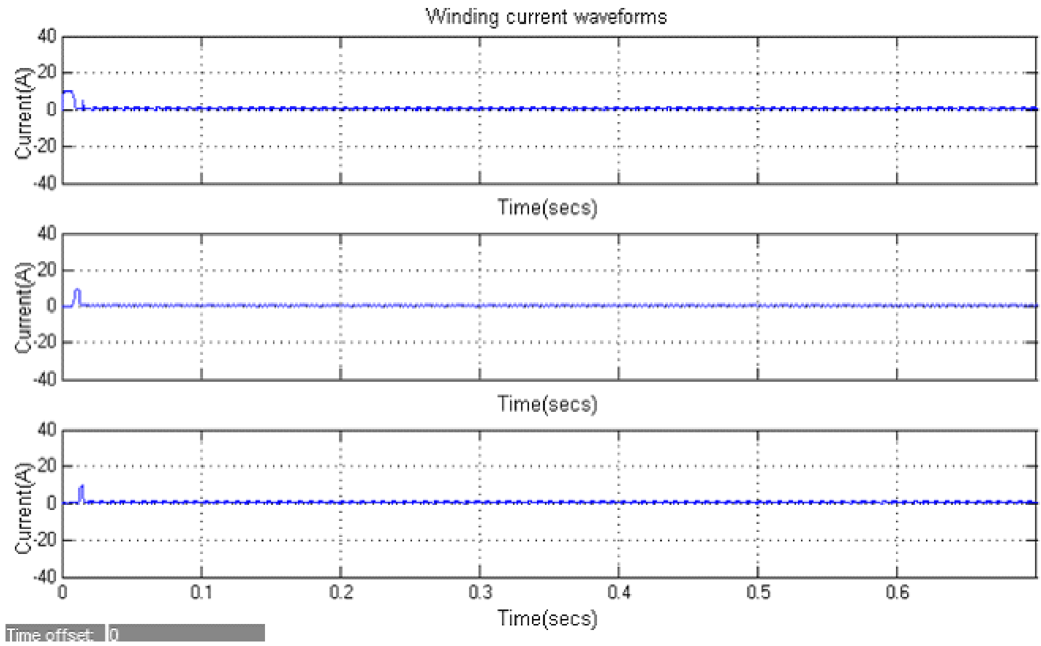

Figure 35. Winding current waveforms

As we can see in Figure 35, after a short-lived wave motion, the current trend is stable. Because of the input torque is 0, the current is approaching 0. With the influence of damping, the current is a bit bigger than 0.

6.1.3 Result of the Rotational Speed

Figure 36 illustrates of the rotational speed waveform:

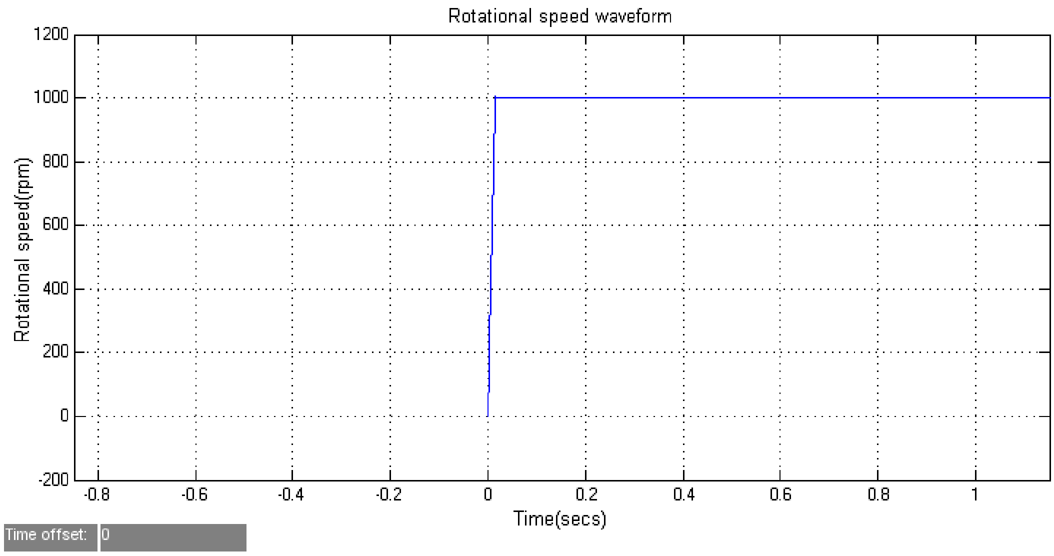

Figure 36. Rrotational speed waveform

As we can see from Figure 36, the rotational speed increases at very beginning and then keeps steady when it meets the setting value. The response time is very short, less than 0.1s, which means it has a good response speed and performance.

6.1.4 Result of the Hall Signals

Figure 37 shows of the waveform of hall signals:

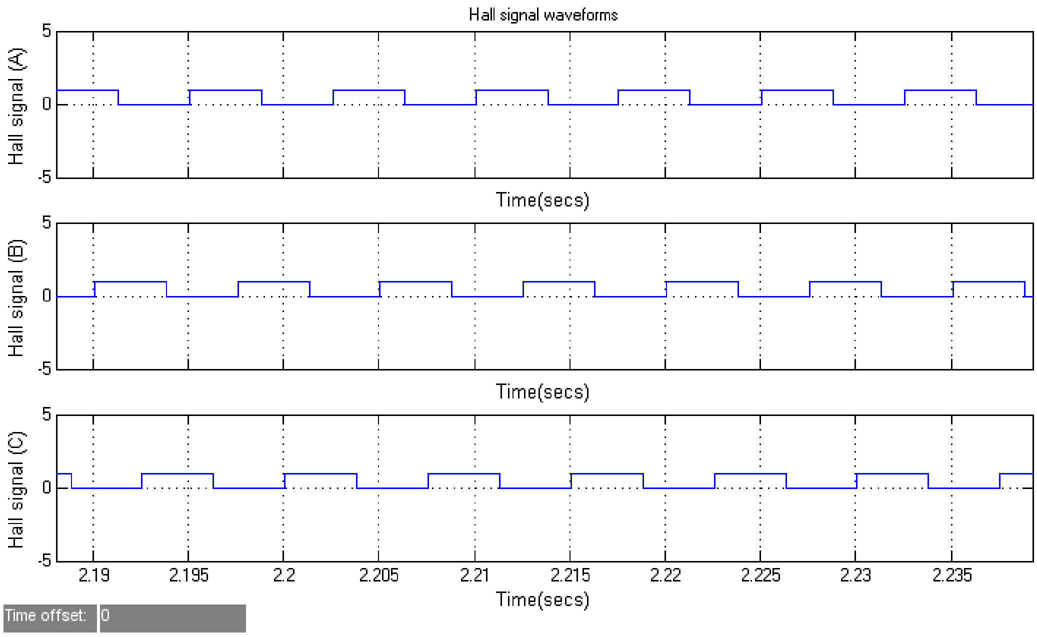

Figure 37. Hall signal waveforms

The hall signals represent the position of the rotor. As shown in Figure 37, the hall signals have followed a cyclical pattern and each phase has a 120° difference, which is same to the hall signals in real life This means the rotor works well and the feedback from the hall sensor has a good result.

6.1.5 Result of the rotation angle

Figure 38 illustrates the rotation angle waveform:

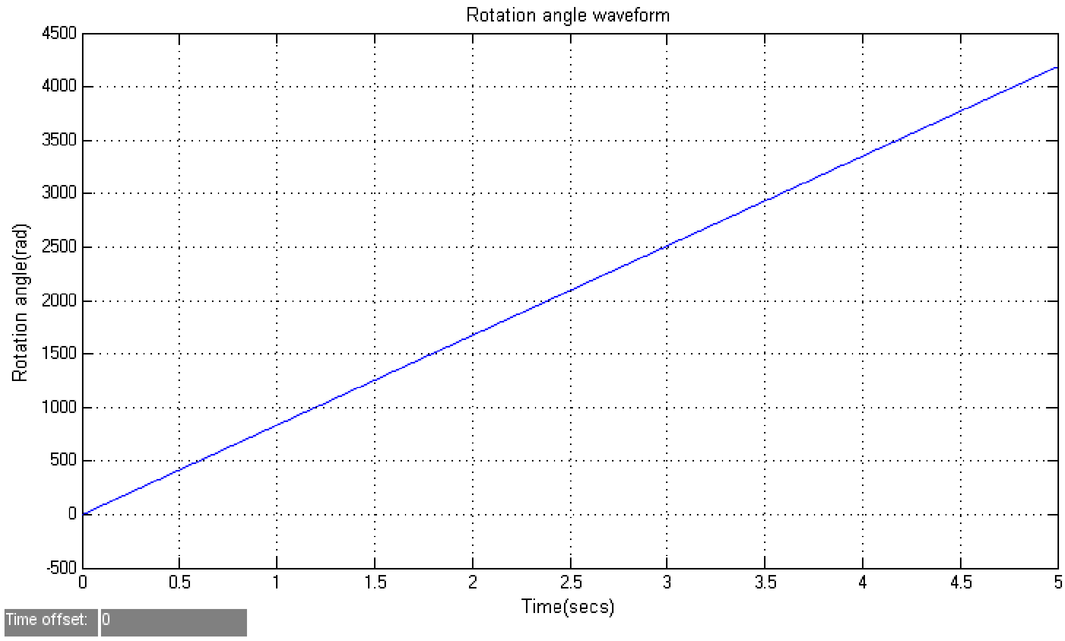

Figure 38. Rotation angle waveform

As we can see from Figure 38, the rotation angle increases with a stable slope coefficient. Because the rotational speed n equals to 1000 r/min, the rotor will rotate 16.67 circles, as the number of pole-pairs p equals to 8, the rotor will rotate 16.67*2Ω*8= 837.50 rad. It is the same to the result given in figure 38.

6.2 Testing of the system

The entire was simulated system by using the testing model in chapter 5.2; we can obtain the result of linear velocity, rotational speed and also the path of the robot. The angular velocity w was set to zero.

6.2.1 Result of the linear velocity

After the simulation of the position setting and testing model, the setting velocity of the robot can be calculated as follows:

The first figure is the setting velocity in X axis; the second figure is the setting velocity in Y axis; the third figure is the setting angular velocity.

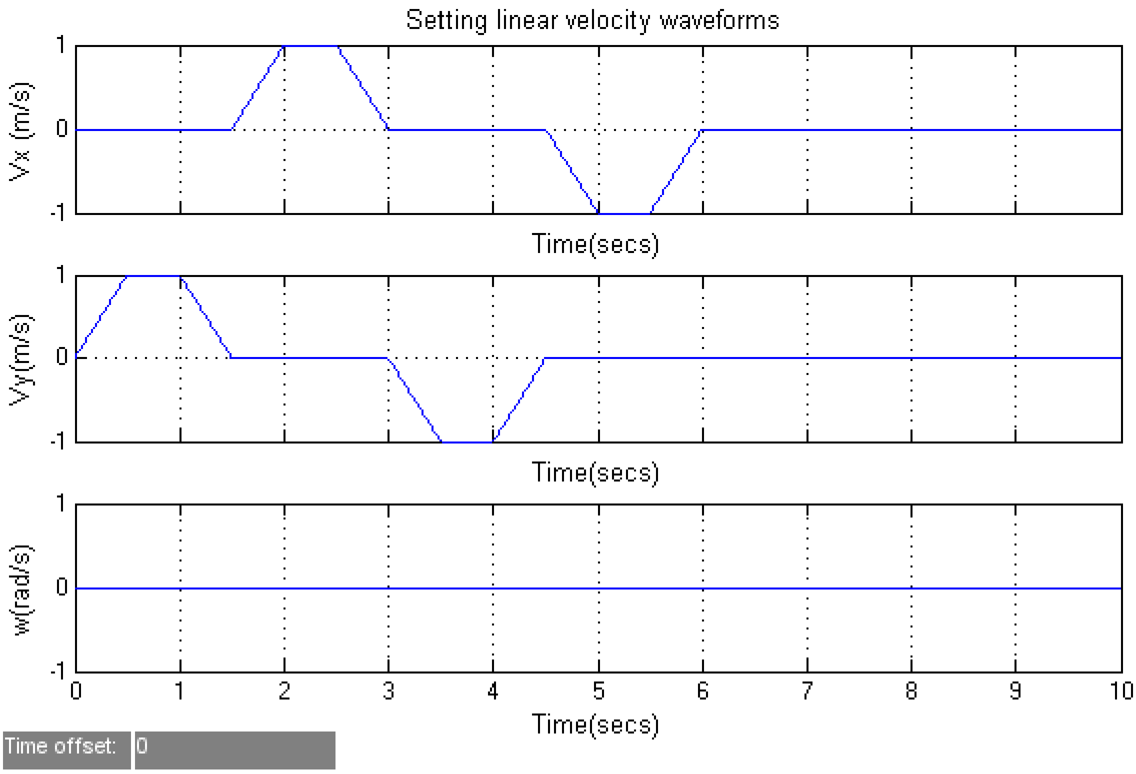

Figure 39. Setting linear velocity waveform

Figure 40 displays the real velocity of the robot after the speed distribution and composition. The first figure is the real velocity in X axis; the second figure is the real velocity in Y axis and the third figure is the real angular velocity.

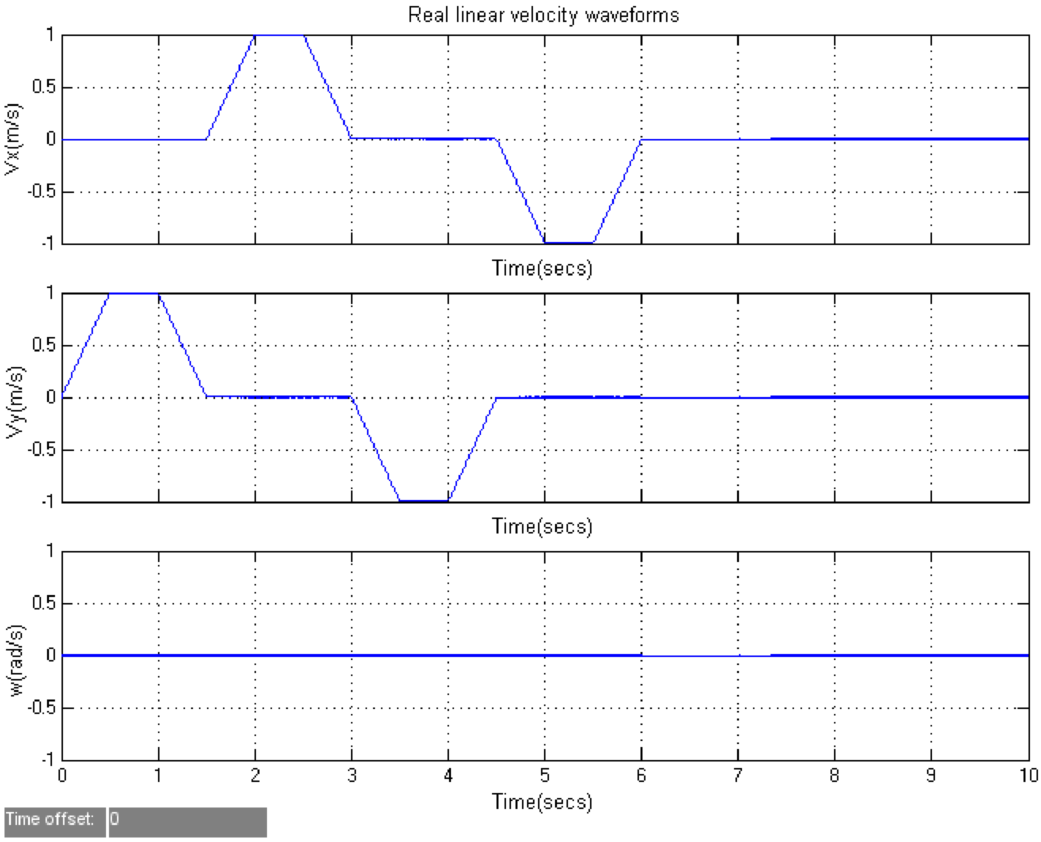

Figure 40. Real linear velocity waveform

As we can see in Figure 40, although the real velocity signals has some small jitters, they are nearly the same to the setting values. Therefore, the entire system has a good performance.

6.2.2 Result of the rotational speed

After the distribution of the linear velocity, the rotational speeds can be obtained. Figure 41 shows the rotational speeds distributed to each motor.

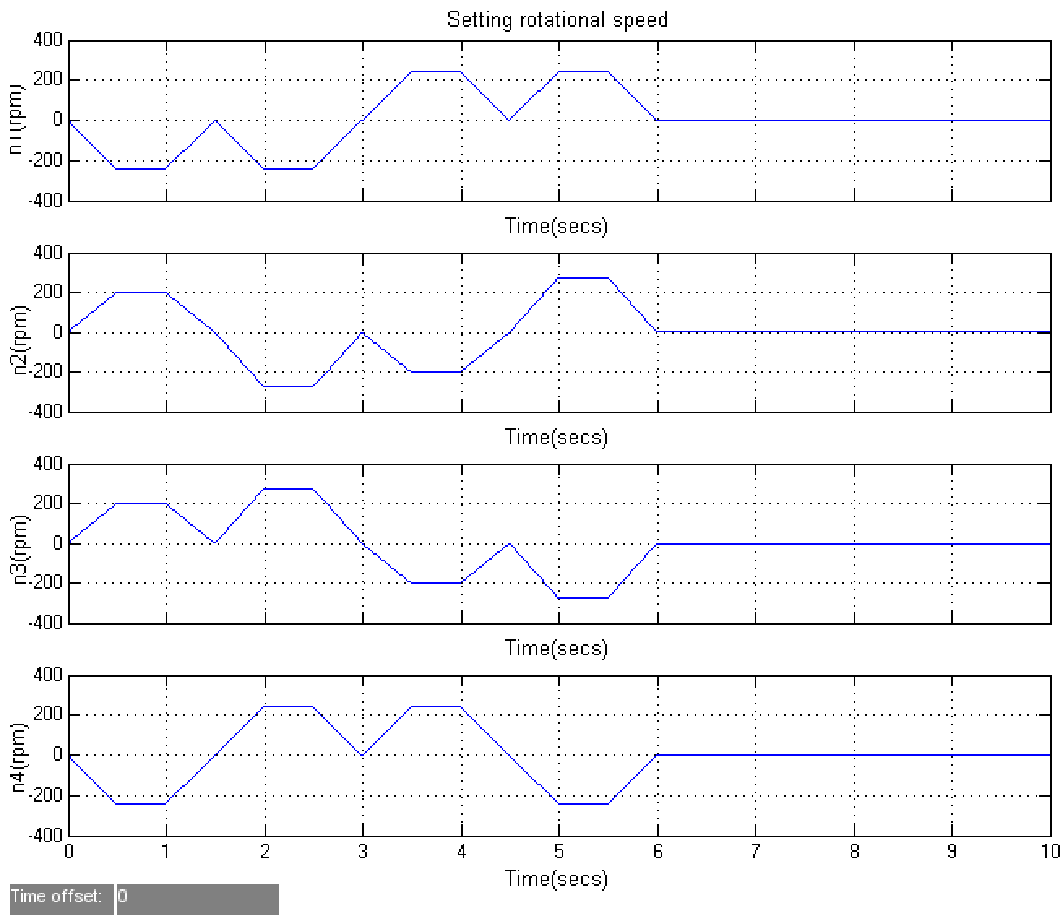

Figure 41. Setting rotational speed

The following figure shows the real rotational speeds of each motor.

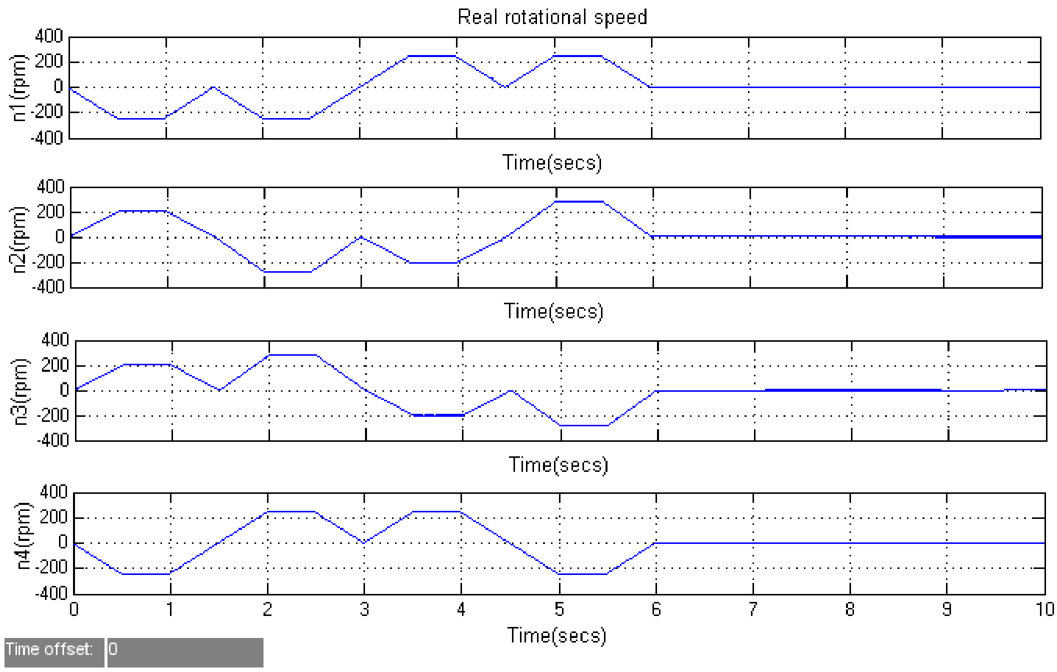

Figure 42. Real rotational speed

There are some small jitters in the real rotational speeds. However, comparing to the setting values, the waveforms of real rotational speeds are similar to the setting values. Therefore, the whole system has a good performance and useful for the simulation of the situation of robot motion control system.

6.2.3 Result of the displacement

After the operation of the system, the displacement of the robot can be obtained. By exporting and matching the signals of position both in X axis and Y axis in Matlab workspace, the following results were obtained:.

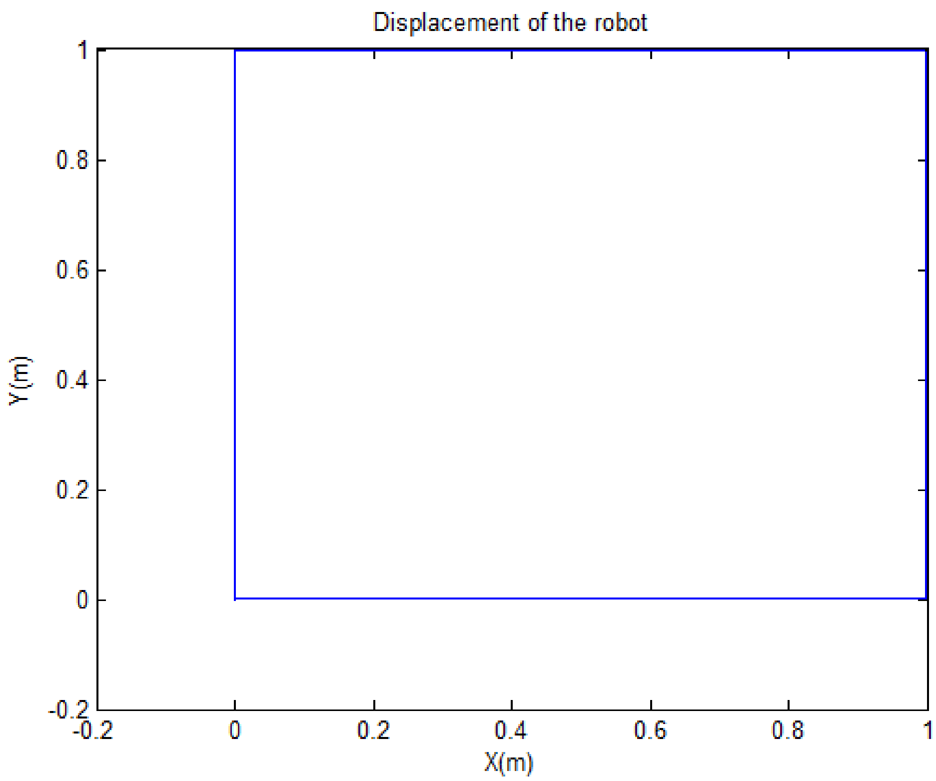

Figure 43. Robot displacement

According to Figure 43, We can see the path of moving robot is like a rectangle as we set before in the test module.

Another testing of the whole system was made as well. Velocity in X axis was set as 1 m/s and Velocity in Y axis as 1 m/s, and angle velocity as 1 m/s. The path of robot can be obtained as follows:

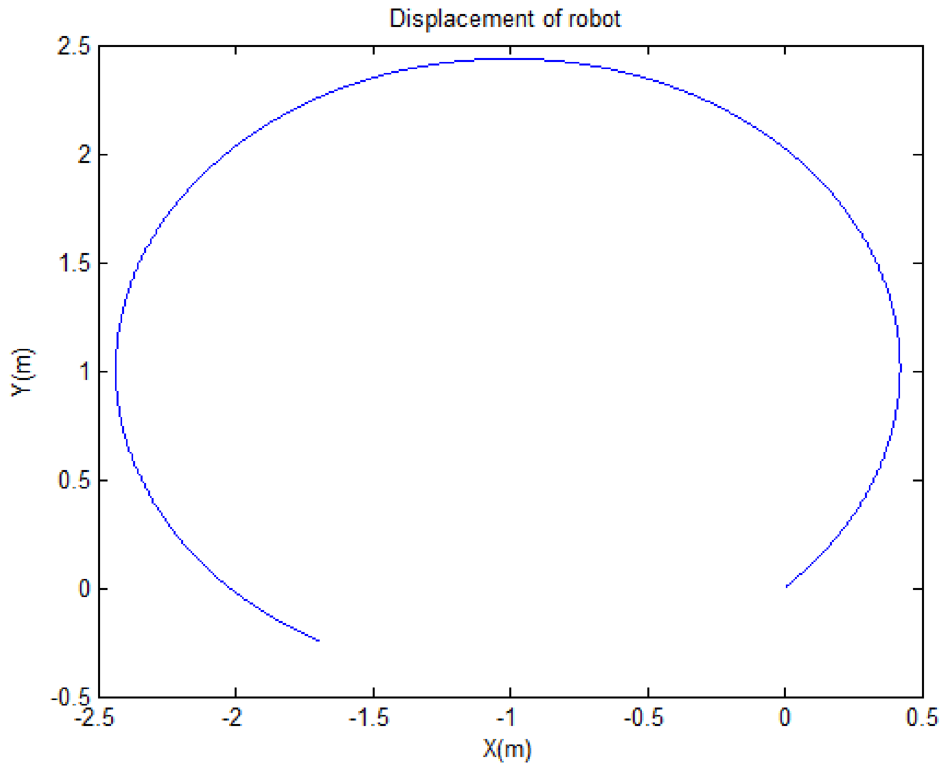

Figure 44. Robot displacement2

As we can see in Figure 44, the robot moved in a cycle and the value in Figure 44 shows that it is has the right motion regular according to the velocity set before. Therefore, we can draw the conclusion that the whole system has been testified reasonably and in a valid way and the performance coincides the simulation results and theory analysis.

7 CONCLUSION

Based on the background of soccer robot, this thesis builds the modeling of soccer robot motion system by Matlab/Simulink. Firstly, Background study introduces the knowledge of soccer robot motion control system, including the structure of robot, drive system of motor, mechanisms and parameters of motor and working process of the whole system. The brushless DC motor was built according to the mathematical theory and mechanism of the motor. The drive system was built for the brushless DC motor based on the motor driving technology, including PID control, current hysteresis regulator and position detection by hall sensors. Matlab Embedded Function module was used to build the velocity distribution model and composition model, which distributes the linear speed of robot to each wheel and synthesize the feedback speed of each wheel to the robot speed. The path of robot could be obtained by analyzing the feedback velocity of the robot. Finally, test soccer robot motion control system was tested.

During the testing, the result shows the right motion regularity according to the setting velocity. Based on the testing result, we can say that the whole modeling system can support the simulation of the soccer robot control motion and has a good performance. Additionally, it also makes contributions to the design and debugging of the real soccer robot motion system, which can be used in the deeper research of the soccer robot.

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